BRUSH SEALS FOR CRYOGENIC APPLICATIONS

N94-23063

Fifth Annual Symposium on Space Propulsion
September 8-9, 1993

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ABSTRACT

Brush seals are compliant, contacting seals and have significantly lower leakage than labyrinth seals in gas turbine applications. Their characteristics of long life and low leakage make them candidates for use in rocket engine turbopumps. Two-inch diameter brush seals with a nominal 0.005 inch radial interference were tested in liquid nitrogen at shaft speeds up to 35,000 rpm and pressure drops up to 175 psid per seal. A labyrinth seal was also tested to provide a baseline. Performance, staging effects, and wear results are presented.

INTRODUCTION

Brush seals are compliant, contacting seals. They are comprised of a pack of small diameter (0.0028 inch) wire bristles set at an angle (typically 40 degrees) to the radial direction, which is sandwiched between a front and back washer. The back washer serves as a mechanical support to prevent the bristles from blowing out downstream. Typically brush seals are designed to have an interference fit with the shaft. Because the bristles are angled, they act as cantilevered beams during shaft perturbations. Bristles under load from the shaft bend away from the shaft. Unloaded bristles relax and remain in contact with the shaft.

Brush seals have shown a significant improvement in leakage performance over labyrinth seals and have been successfully operated for thousands of hours in gas turbine applications. (Ref.1) These characteristics of low leakage and long life make brush seals candidates for use in rocket engine turbopumps, particularly for space-based engines and reusable launch engines. The low leakage requirement is most critical in meeting the wide-operating range requirement of space engines in which seal leakage can significantly reduce engine performance at low thrust levels.

Testing of brush seals in liquid nitrogen was conducted at the NASA Lewis Research Center at shaft speeds up to 35,000 rpm and pressure drops up to 175 psid per seal. A labyrinth seal was also tested to provide a baseline for comparison. Performance, staging effects, and wear results are presented.

PERFORMANCE

Two-inch diameter brush seals with a nominal 0.005 inch radial interference were tested in liquid nitrogen. A 12-tooth, 0.00513 inch radial clearance labyrinth seal was tested in liquid nitrogen as a baseline. Measured and predicted labyrinth seal performance were in good agreement. As expected, there was no speed dependence in the labyrinth seal. Leakage of a single brush seal was two to three times less than the labyrinth seal. Shaft rotation is necessary to properly seat the seal and achieve the lowest leakage. As expected, the fluid temperature rise across the seal increases with increased shaft speed due to frictional heating between the brush and rotor. An increased pressure drop across the seal, which caused a higher leakage rate, resulted in decreased fluid temperature rise across the seal because more flow was available to carry the heat away. A blowout test at a shaft speed of zero rpm was conducted to determine the maximum pressure a single brush seal could withstand. A pressure gradient of 550 psid was applied to a single seal with no blowout occurring. At this condition the instrumentation became saturated. The power loss due to a single brush with a pressure load of 175 psid at 35,000 rpm was 3.75 Btu/s based on the mass leakage flow through the seal and the fluid enthalpy change between the seal inlet and exit.

STAGING EFFECTS

Staging effects were studied. Two brushes separated by two brush widths leaked about half as much as a single brush. However, two brushes tightly packed leaked about 75% as much as a single brush. As expected, the fluid temperature rise with two or three seals is greater than that with just one brush seal. The maximum temperature rise, measured at a shaft speed of 35,000 rpm and pressure drop across the seal of 25 psid was 95 R for three brushes and 56 R for one brush. In the configuration of three brushes evenly spaced, the leakage performance of the first two seals was nearly equal, but approximately half that of the last brush at zero rpm. However, at 35,000 rpm the leakage performance of each of the seals was nearly equal.

WEAR

The rotor was made of Inconel 718 and the bristles were made of Haynes-25. Shaft rotordynamics were very good; nominal rotor orbits were less than 0.2 mils in diameter. A maximum orbit of 1.0 mil diameter did occur for a brief time during testing. The maximum shaft speed was 35,000 rpm and the maximum surface velocity was 305 ft/s. Four and one-half hours of shaft rotation time was accumulated. This is 36 times the 450 second mission life of an RL-10 rocket engine. After testing, profilometer traces were taken across the axial length of the rotor at four locations: 0, 90, 180, and 270 degrees. The maximum groove depth measured was 0.0010 inch and the nominal groove depth was 0.00075 inch. Some bristle wear did occur; approximately 1-3 mils. Bristle wear is difficult to quantify due to uncertainty in bristle bore diameter measurements. An optical comparator was used to make these measurements and it was found that the bore diameter can vary by 7.5 mils. A few bristles (approximately 10) appeared to have melted. This may have occurred at some early test conditions of shaft speed, but no pressure gradient across the seal. These test conditions were discontinued.

REFERENCES

1. Ferguson, J.G.: Brushes as High Performance Gas Turbine Seals. ASME Paper 88-GT-182, June 1988.
2. Morrison, G.L., et.al.: Labyrinth Seals for Incompressible Flow, Final Report for NASA Contract NAS8-34536, Texas A & M University, November 30, 1983.

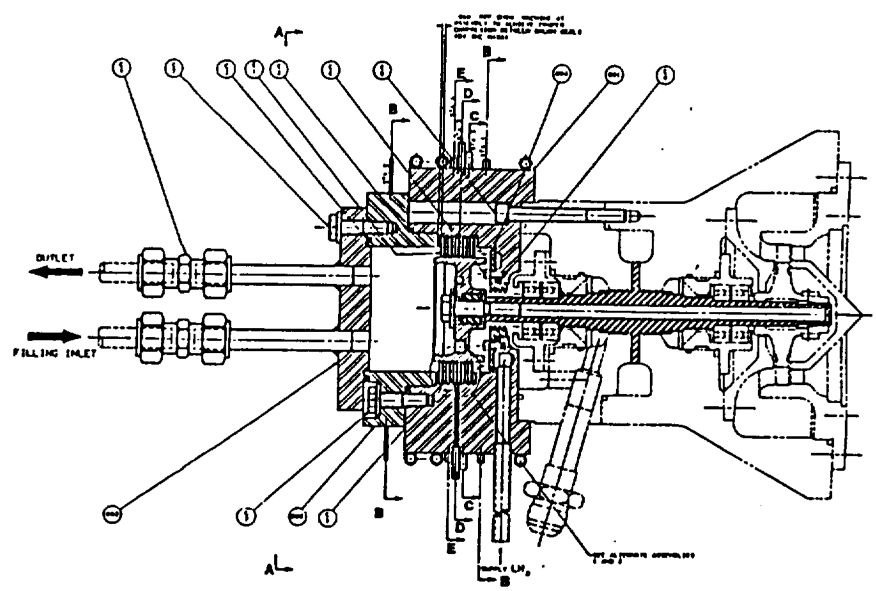

Figure 1.
Cross section of cryogenic brush seal tester.

NOMINAL GEOMETRY

ROTOR:	Outside Diameter	2.0000 inch
	Surface Roughness	32
	Material	Inconel 718
	Coating	none
BRUSHES:	Manufacturer	Technetics
	Outside Diameter	2.8190 in.
	Frontplate I.D.	2.4000 in.
	Bristle I.D.	1.9900 in.
	Backplate I.D.	2.0220 in.
	Axial thickness	0.142 in.
	Backplate thickness	0.056 in.
	Bristle angle	40 degrees
	Bristle diameter	0.0028 in.
	Packing density	3000 bristle/inch-circumference
	Plate material	Hastelloy-X
	Bristle material	Haynes-25

CALCULATED PARAMETERS:

Radial interference	0.0050 in.
Radial clearance between backplate and rotor	0.011 in.
Radial distance between backplate & bristle id's	0.016 in.
Radial distance between frontplate & bristle id's	0.205 in.

Table I.

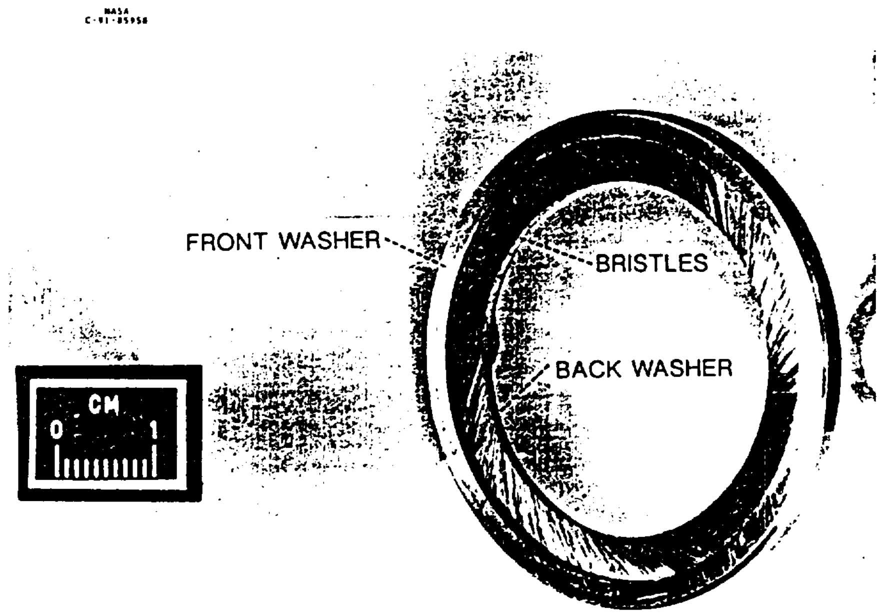

Figure 2.
A typical brush seal.

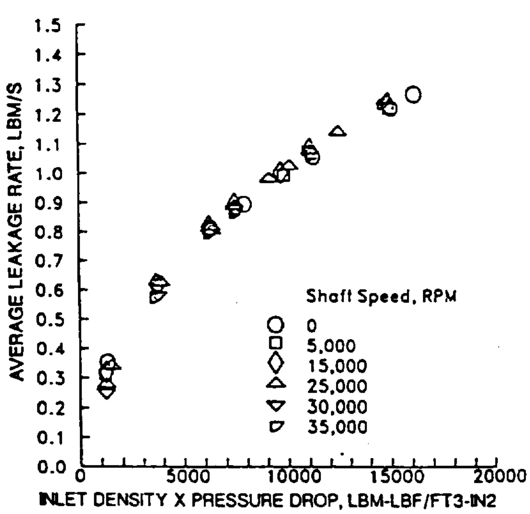

Figure 3.
Leakage rate of a 12-tooth labyrinth seal with 0.00513 inch radial clearance in liquid nitrogen as a function of seal inlet density x pressure drop across the seal.

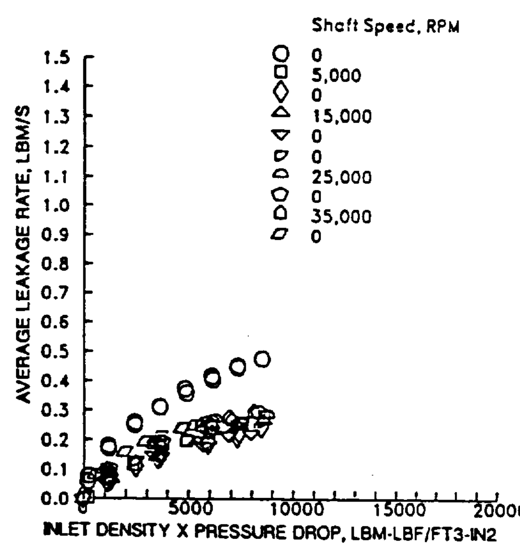

Figure 4.
Leakage rate of a single brush seal in liquid nitrogen of 0.004375 inch radial interference as a function of seal inlet density x pressure drop across the seal.

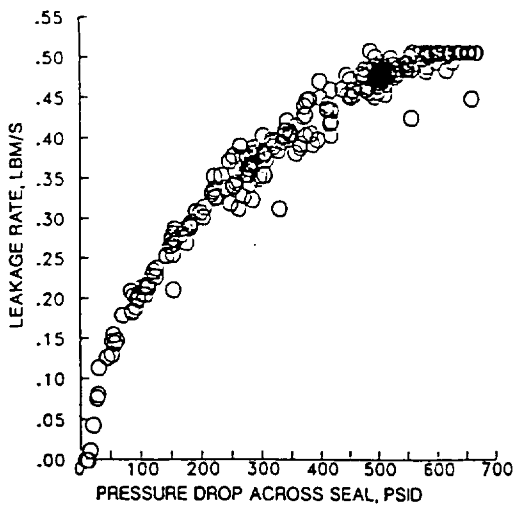

Figure 5.
Blowout test of a single brush seal in LN2 at zero rpm.

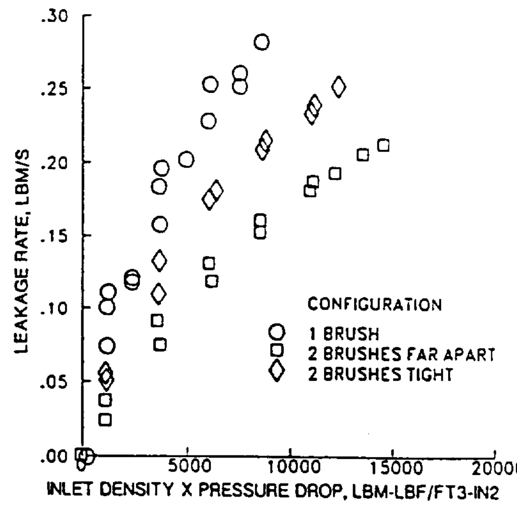

Figure 6.
Comparison of LN2 leakage performance for a single brush, two brushes separated by two brush widths, and two brushes tightly packed at 5,000 rpm.

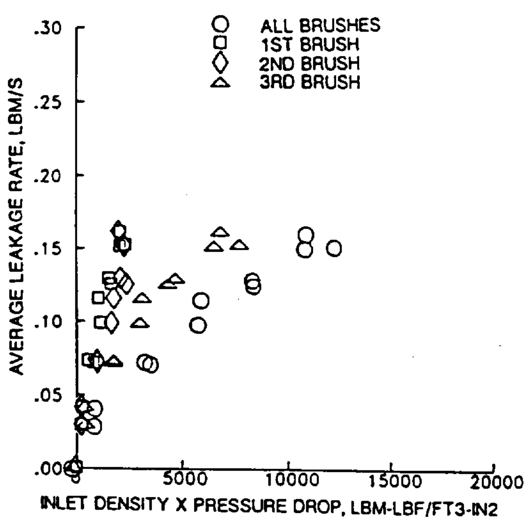

Figure 7.
Comparison of LN2 leakage performance for each each seal in the 3 brushes evenly spaced configuration at zero rpm.

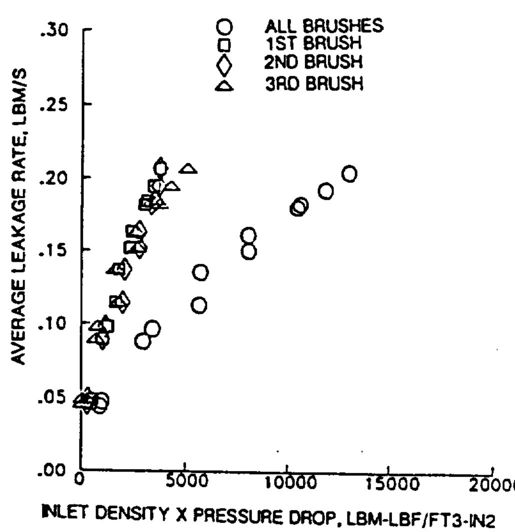

Figure 8.
Comparison of LN2 leakage performance for each seal in the 3 brushes evenly spaced seal configuration at 35,000 rpm.